FROM THE TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA
SECOND SERIES—1898-99

VOLUME IV SECTION III

MATHEMATICAL, PHYSICAL AND CHEMICAL SCIENCES

ICE FLOODS AND WINTER NAVIGATION OF THE LOWER ST. LAWRENCE

By T. C. KEEFER, C.M.G., C.E.

FOR SALE BY
J HOPE & SONS, OTTAWA ; THE COPP-CLARK CO., TORONTO
BERNARD QUARITCH, LONDON, ENGLAND

1898

I.—*Ice Floods and Winter Navigation of the Lower St. Lawrence.*

PRESIDENTIAL ADDRESS TO SECTION.

By T. C. KEEFER, C.M.G., C.E.

(Read May 25, 1898.)

The winter ice floods of the St. Lawrence are distinguished from those produced by ice in other rivers more to the south, in that the latter are the direct result of thaw and rain throwing increased quantity of water into the stream while covered with ice, breaking this up and forming dams with it upon the river bottom ; whereas those of the St. Lawrence occur when there is the least water in the river as well as less ice than at a later period of the winter. The spring floods are generally higher, but like the winter ones are the direct result of ice, and are produced in the same manner but usually with a greater quantity both of ice and water.

The St. Lawrence, flowing through such impounding reservoirs as the five great lakes, is not exposed to overflow from any excess of rainfall, its range between high and low water being generally less than one-tenth of that of the Ohio, although its low water discharge is nearly nineteen million cubic feet per minute. Its ice floods only occur at three points below each of the great rapids above and below Lake St. Francis, and below Lake St. Louis, and, with the exception of this last, are confined to a short section of the river.

Since 1852 water levels have been recorded at Montreal. Previous to that year the only floods, the heights of which have been determined, are those of 1838, '40 and '41. The earliest reference to this winter rise is that of Père Barthélemy Vincent, S.J., in 1643, when Maisonneuve, the founder of Montreal, on the threatened inundation of his newly-erected cantonment resorted to prayer and pilgrimage to avert a disaster. This rise was not near our flood level of to-day. From its exposed position it must have suffered from ice shoves at a later date. Since this we have newspaper references to "floods" in 1791, '98, 1810, '23, '33, '36, '38, '40, '41, '48, '61, '65, '69, '73, of which the heights of all previous to 1838 are unknown. Few probably reached our flood level, and for the earlier ones there was little exposed to damage.

The winter flood is the result of long-continued cold weather, which while it diminishes the land water coming in, manufactures ice in the greatest quantity, which a strong current disposes of in such a way that, without forming a dam, the ice so obstructs the flow as to cause a rise of water which in some years becomes a flood. This occurs in January, at the coldest season of the year, and, though inferior in height and extent

to the April ones which occur on the departure of the ice, is more distressing from the greater coldness both of the weather and the water. There is an annual winter rise, seldom less than ten feet above summer level, at Montreal, but it does not become a " flood " until it exceeds twenty feet or more.

The average rise on the taking over of the river in January is about twelve feet, and the average rise on the departure of the ice in April is about fifteen feet, the increase in this average being due both to the all-winter accumulation of ice, and the spring inroad of water.

After floods in 1838, 1840 and 1841 a revetment wall was constructed by the Royal Engineers in front of the principal part of the city, the top of which was twenty-one feet above summer level of harbour and was supposed to be one foot higher than the highest flood—but since its construction the river has gone over this eight times. The top of this wall is known as " flood level " because, until the river rose above it, there was no general inroad of water all along the line—although there were about ten miles of streets inside it, which were about four feet lower than the wall, and were flooded through the sewers. This condition continued until 1887 when, after three floods in succession, (the second of which, that of April, 1886, was the highest ever known), a temporary dyke was built, in that year, upon the top of this revetment wall, upon the recommendation of a Royal Commission which was appointed in 1886 immediately after the second flood. There has been no flood since until March of the present year, on which occasion this dyke prevented the flooding of many miles of streets, upon some of which the water would have stood over six feet deep.

In the last sixty years there have been four winter floods, ranging from one to two feet above flood level and eight spring floods—the last being the one of this year. The highest of the spring floods, that of 1886, went nearly six feet over the flood level, putting about ten feet of water on the lowest streets. While floods have occurred at an average interval of five years, they have taken place as frequently as three years in succession, or with only an interval of one year between them, Moreover, in this period of sixty years there have been intervals of eleven, twelve and thirteen years without any flood. Partly owing to these long exemptions no recent protection work was undertaken until the dyke was built in connection with efficient pumping stations for throwing the sewer and surface water over it, when all outlets into the river were closed.

The duration of a flood may be a few hours, or a week, or more. The flood of 1838, which was the highest winter one recorded, lasted fourteen days, but was probably less than half of this time above the " flood level," which level was established by the revetment wall several years later.

Previous to 1850 all the recorded floods were winter ones, and then followed an exemption from winter floods of thirty-eight years, until Janu-

ary, 1886, when the last winter one took place. Moreover, there has never been a winter flood recorded in December, although the river has been closed in that month, nor a spring one in March until this year, although the river has been broken up and the ice has departed in that month.

There is a difference of ten to fifteen feet in the winter rise of different years. The flood in April, 1886, rose 27 feet above the summer level of Montreal Harbour ; but there have been winters in which the greatest rise did not exceed 12 feet above that level. The highest spring rise above ordinary low water was in April, 1886, 27 feet. The lowest spring rise was in March, 1860, 10 feet. The highest winter rise was in January, 1838, 23½ feet. The lowest winter rise was in January, 1873, 10½ feet. "Lowest water" has gone four feet below "ordinary," giving an extreme range in the harbour of 31 feet.

The winter floods are caused by the accumulation of floating ice during continued severe weather extending from November into the New Year. This ice descends the river until it is arrested by the ice bridge which forms with the first severe frost at Lake St. Peter, and some of it may come from many miles above Montreal, but after Lake St. Louis is closed above Lachine it is all produced in the river below.

The winter level of Lake St. Peter is four to five feet higher than the summer one, while the river below is open ; but when the river is closed down to the Platon the lake is raised seven or eight feet above summer level.

The ice "takes" in November in the bays and along shores and extends outwards to the edge of the channel, which never freezes over (on account of the strength of its current), but remains open down to the ice bridge until it is covered over by the floating ice which extends the ice bridge up stream all the way to the Lachine Rapids. The bay and shore ice of varying width and thickness due to the weather and the stage of flow in the river, and often miles in length, is pried off from its shore attachment by the rising water caused by the packing which is going on at the ice bridge and swings out into the channel where it is carried down, as bridge material, and is broken up against the solid ice barrier, forced under and tilted on edge, giving a ragged outline to the bridge both in air and water. The supply of this bordage ice varies with the weather, and the bays and shores may furnish more than one crop of it before the ice bridge is completed. A mild week or two arrests the advance of the ice bridge for want of material, and new bordage ice may form on a higher level and be again dislodged and drawn into the channel.

In 1886 the ice bridge took at Nicolet, the lower end of Lake St. Peter, on 4th of December, and the lake was covered to Stone Island (20 miles above) in thirty hours. It reached Sorel, seven miles further on, on the 6th in fourteen hours ; Verchères, 23 miles above, on the 9th inst. in

78 hours. After five days' thaw it reached Varennes on 16th, nine miles in seven days. The upward march to Longue Pointe, seven miles, was made in two days of cold weather. Mild weather followed and the next four miles, to Hochelaga, was covered in eleven days, on the 29th. In the next two days the channel was filled up to the foot of the Lachine Rapids, a distance of over ten miles. Thus the whole of the river channel, for 55 miles above Lake St. Peter, was covered over with drift ice in about three weeks.

When the ice bridge is above Longue Pointe and approaching Hochelaga it requires more time and bridge material to build up sufficient obstruction so as to force up the river level and flood out the rapids between Hochelaga and the Laprairie basin, which have about nine feet fall in three miles. This narrower and shallower section opposite Montreal cannot retain as much of the ice-pack as the sections above and below it, and therefore the current St. Mary (immediately below Montreal harbour) and the Sault Normand (immediately above it) combine their forces to drive all the ice they receive as far as possible below them until they have produced a pack, which by raising the river level will enlarge their own dimensions, when they become quieted down and covered over in common with slower sections of the river. It is in the struggle to maintain sufficient water-way, in this quarter, above, opposite to, and below the city that those great convulsive efforts of the river, commonly called "shoves," take place. These may drive some obstructing mass entirely out of the river, or force a greater one into the channel, suddenly throttling its waterway and producing a rapid rise, which may become a flood. The greater rise opposite Montreal is doubtless due to the greater fall in the river here than anywhere else below the Lachine Rapids, and to its efforts to adjust itself to the winter conditions of slower current in a wider and deeper channel.

The spring floods are produced in the same manner as the winter ones, but owe their usually greater height to the greater quantity of ice at the end of the winter and to the additional quantity of water from the land. There is no ice gorge or dam resting on the bottom in either case, although there is enormous ice congestion above and below Montreal and some partial dams in shoal water inshore may be temporarily formed by one shove, and as rapidly ejected from their site by another. Large quantities of ice are driven ashore above the water line and there left behind by the river—which remain until melted *in situ*—or are thrown into the water where, as on the wharfs or elsewhere, they obstruct access to the river.

The wonderful rapidity of the rise caused by a "shove" in a great river like the St. Lawrence was shown in April, 1887, before the dyke was constructed, when the water, which stood one foot below flood level, rose 5 feet 5 inches in one hour and twenty minutes (65 inches in 80 minutes),

about $\frac{3}{4}$ inch per minute. A shove upon the same day above the Victoria Bridge drove a sheet of ice upon the sloping masonry of the abutment, striking telegraph wires which were placed seventy feet above low water mark. At Longueuil, where the water rose twenty feet above summer level, it poured into the village, carrying huge blocks of ice which dealt destruction to houses, telegraphs, fences, etc., and rose five feet in ten minutes in the waterworks station. The most rapid rise recorded is that of April 14th, 1896, three feet in ten minutes—one foot in one and a-third minutes.

Before the revetment wall was constructed these shoves drove the ice-fields up the sloping beach to such a height beyond top bank that they broke by their own weight and piled a rampart of ice thirty feet high in front of the buildings they could not reach and out of which the terrified inmates escaped (on this ice) by the third story windows. Unprotected stone buildings on the river bank were levelled to the ground, and in 1823 a whole family of five were crushed to death in their shanty, upon which the ice piled fourteen feet high. Exposed stone warehouses were simply and cheaply protected by stout poles slanting from them which turned the ice upward until it broke and piled itself as a protection wall in front.

The illustrations of ice "shoves" in front of Montreal are the more liberal because they have ceased since the completion of the guard pier —a long and narrow artificial island placed in the middle of the river opposite the harbour, and is intended to allow the erection of permanent warehouses upon the wharfs. In this connection it is to be remembered that the temporary dyke was completed before the guard pier was commenced.

On the break-up and departure of the ice during the great flood of April, 1886, when the water in Montreal harbour rose twenty-seven feet above the summer level, the ice obstructions below Hochelaga gave way so suddenly before the pressure caused by this great head, that the ice-laden flood-wave, which started at twenty-seven feet, dropped three feet in the first mile and to twenty feet at Longue Pointe, which elevation it maintained for a distance of thirty miles, and reached Sorel with a height of sixteen feet above summer level. This wave started from Montreal about noon and reached Sorel (forty-five miles distant) at 10.00 p.m. the same day, flooding in its course, with ice and water, the banks on both sides of the St. Lawrence wherever they were not above this flood-wave level.

It was to the packing of these leagues of bordage ice covered often with snow, and always in evidence when passing down the channel, that the winter rise of the water was attributed. Little attention was given to patches and streams of lead-coloured slush-ice almost even with the surface and only visible near the shore which sometimes, especially in very

cold weather, was passing down; and was probably considered only as cementing material for the ice bridge. Moreover, from the fact that when the river attains its highest winter level (which is after it is completely ice-covered and after a final "shove" or a flood) it almost immediately begins to fall, it was supposed that thereafter no further addition to the ice pack below the city did or could take place.

The Lachine Rapids and about five miles of the river above, as far as Lake St. Louis, are open water throughout the winter. It was known that in this quarter large quantities of frazil and anchor ice were produced in the coldest weather, and sent over the rapids, but it was supposed that this material was arrested in the wide water below the rapids, where ice dams were known to form and "shoves" to take place during the winter.

The Royal Commission of 1886,[1] with a view to ascertain the cause and, if possible, suggest a remedy for the floods at Montreal, carried out an extensive and careful survey of the ice, embracing two winters, measuring the thickness of ice and depth of water over more than twenty miles below the Lachine Rapids. They found that while there was everywhere in the channel a varying quantity of water underneath the ice, in many places there was a much greater depth of ice than water, and this forming no part of the solid covering of the river or broken bordage ice, but "frazil" or anchor ice clinging to the underside of the surface ice and extending downward in some cases nearly forty feet below the surface of the river. These "dependencies" formed a series of inverted shoals which, without causing abrupt elevation at any point, so reduced the waterway and increased the friction in the closed channel as to compel a rise of the river all along the line in order to obtain greater velocity for its water and more room for its ice. This increased velocity extended the range of travel of anchor ice under the surface covering. It was seen through air-holes in the ice passing down opposite Montreal, throughout the winter; having traversed the length of Laprairie basin without having been arrested by friction and frost, as sooner or later takes place lower down.

The Royal Commission of 1886 established the fact that this anchor ice was not only the principal factor, but in their judgment the sole cause of the floods at Montreal; that is, that while a winter rise of the river might be produced every year by the snow-laden solid ice floated down, it would never reach flood dimensions without the aid of this anchor ice manufactured above the city and passing down into cold storage below it, where it is out of the reach of any change of temperature.

[1] This commission was composed of the following engineers: Thos. C. Keefer, Ottawa, chairman; Henry F. Perley, Ottawa, chief engineer Public Works; John Kennedy, Montreal, chief engineer Harbour Commission; Percival St. George, Montreal, city engineer.

In the Laprairie basin, above Victoria Bridge, there was found more anchor ice than water. Below Montreal, between Isle Ronde and Longue Pointe, the quantity was equal to the water, while between Isle Ronde and the Victoria Bridge, where there is a summer fall of nine feet in the river, there was thirty per cent of anchor ice and seventy per cent of water. In these percentages no account is taken of the solid surface covering of the river.

The cubic measures of anchor ice in March were :

	Cubic Yards.
Victoria Bridge to Lachine Rapids, anchor ice	171,228,200
" " " Isle Ronde, " "	12,114,355
Isle Ronde to Longue Pointe, " "	45,443,417

There was three times as much anchor ice above Victoria Bridge as between it and Longue Pointe, but, though above the city, it may play a very important part in the spring flood by coming down upon a blockade below it, and thus force the river above flood level.

The principal packing of the ice extends over twenty miles of river below the Lachine Rapids, or as far as Varennes. In this mileage the "field," or solid surface ice amounts to about one hundred million cubic yards, the frazil or anchor-ice to 352 million, while the clear water is 467 millions of cubic yards. The anchor-ice, being more than double that of any other kind, warrants the conclusion that it is the cause of the floods.

The following are the heights above low water at which the river stood when it closed in December, 1886, and before it rose for the break-up in the end of March, 1887 :—

	Dec., 1886.	March, 1887.
Sorel	4 ft. 2 in.	5 ft. 5 in.
Verchères	10 " 2 "	8 " 1 "
Varennes	11 " 2 "	8 " 5 "
Longue Pointe	11 " 5 "	9 " 6 "
Hochelaga	15 " 9 "	11 " 2 "
Montreal	16 " 11 "	....
Laprairie	9 " 9 "	10 " 4 "

The rise at Sorel in face of the fall between it and Montreal was due to an ice bridge at the Platon. That at Laprairie was caused by winter flow of anchor-ice over the Lachine Rapids.

Anchor Ice.

Ice which can first form upon or attach itself to the bottom of a river, sometimes to such an extent as to raise the surface level, and, when driven from this position by temperature changes, arise, move down and

pass out of sight and there attach itself to the frozen top of the river where it can defy the winter changes of temperature and maintain its position until it is carried off with its floating anchorage by the break-up in spring, is what has to be reckoned with as the chief factor in the winter floods of the St. Lawrence.

Much has been written about anchor ice, without settling the question as to how it forms upon, and why it arises from, a river bottom. Our Transactions contain three papers in which it is dealt with. In Dr. Robert Bell's paper, in Trans. of 1886, Section III., page 85, he describes it as "forming as a spongy mass in cold weather on the stones in the bottom "of open rapids, in brooks and rivers, and sometimes under the open "water which is often found at the outlet of lakes. In clear weather it "gathers abundantly around the boulders, and when these rest on other "stones, and have only a narrow base of support, they are sometimes "buoyed up by their icy envelope and floated or rolled away by the "force of the current. Boulders of considerable weight have been known "to be lifted by these means."

"When the weather becomes milder, *or the sky overcast*, the frazil "rises to the surface and floats off like a mixture of snow and water. "Although the water may remain open beneath bridges, or overhanging "rocks and large fir trees, frazil is not observed to form in such "situations."

The late Dr. Sterry Hunt (he says) attributed the formation to terrestrial radiation and as analogous to the formation of hoar frost *in clear weather*, and Dr. Bell continues : "*In rapids* the surging and churning "motion would carry down the coldest water from the surface probably "charged with multitudes of fine ice crystals and throw it against the "stones on the bottom."

The above description (without the italics) is, I believe, correct, and I would only supplement it in one or two particulars.

1. The greater formation of anchor-ice both in area and thickness is often in the deeper open water above the rapids. In the shallower rapids it forms and rises more frequently, and in less severe frosts, probably because radiation is more rapid and sun penetration greater in shoal than in deep water, and from the more rapid flow of the ice-cold water chilling the stony bottom. In long-continued, extremely cold spells of several days' duration it may grow, in a rapid, to a very considerable depth and form a dam, raising the whole water surface. When this gives way we are not able to say whether it has yielded before the increased head of water, or from the relaxation of its hold upon mother earth, which follows a change of temperature.

2. It has been known to continue for days and nights on the bottom and attain great thickness, without a clear sky overhead, but with the thermometer always below zero, Fahr.

3. The very large boulders which are picked off the shoals below the rapids and dropped in the ship channel below Montreal are lifted (I believe) by anchor-ice lodged under the surface-ice. By the sudden, and often considerable, elevation of the field-ice to which it is attached, (which may be caused by a "shove" before the river "takes" in January), the whole may be driven upon or over a boulder shoal, and settle down with the falling water enveloping a boulder with its saturated slush, out of which all water is expressed, by downward pressure of the surface-ice, during the winter fall of river level, and thus form a solid mass. These icy "islands" are seen as "hummocks" after the winter lowering of the river, when the compressed anchor-ice beneath holds up the surface-ice much above the water level. When the whole field is lifted by the spring rise of water the boulder accompanies it (a mere pebble in proportion to the size and lifting power of acres of ice perhaps twenty feet thick in some places) and is dropped as soon as warmer water in the river releases it from its icy matrix.

4. It is not only "in the rapids," but everywhere where there is open water in the river, that the colder surface water is carried to the bottom. Anchor-ice has been found at least two feet in depth on the bottom in over twenty feet of water in the river above the Lachine Rapids. This is only during the severest weather. Although the temperature of the water may not descend perceptibly below the freezing point, while that of the air is over twenty below zero, it is under these circumstances this deep river bottom produces anchor-ice, and when this ice rises, as it does in floes of considerable size, it does so with decided force from such a depth, projecting its top into the air and falling back with a hissing sound due to the rapid drainage of its above-water portion. It is also known that at the time of this formation upon the river bottom the flowing water is loaded with fine ice crystals (to the formation of which, I think, the cold surface-air is a necessary factor) and as these are carried to the bottom the presumption is that they are picked up by a condition of river bottom which does not exist at other times which, if not actually frozen, has this power of attraction for these passing crystals by which alone, I believe, anchor-ice is formed. Whether the river bottom is frozen by radiation into space or into an intensely cold atmosphere at the surface of the water, or whether this is produced by the continued friction of an ice-laden current of the coldest possible water, the result is the same and is fortunately limited to short and infrequent periods of severe winters.

After the spring break-up, when large masses of ice are driven ashore by the final "shove," ice floes have been found on the beach partly composed of several feet of anchor ice to the bottom of which frozen gravel was attached.

In the last two volumes of the Transactions of this society an important contribution to this question was made by Mr. Howard

T. Barnes, of McGill University, whose experiments in the Lachine Rapids and elsewhere, upon the temperature of anchor ice and its surroundings with a differential platinum thermometer were the first of their kind. Mr. Barnes ascertained that anchor ice apparently grows upon dark-coloured rocks easier than upon light-coloured ones. He adopts radiation as the cause of formation and shows that the thermometer "when left undisturbed was cooled by radiation below "the temperature of the surrounding water, so that ice formed on "the stem," but he considers it "doubtful whether frazil could be-"come attached to the bottom previous to the formation *in situ* of "a layer of ground ice." If a previous frozen bottom is conceded the doubt would be whether frazil would attach itself to this—or only to ice previously formed *in situ*—that is, ice which has grown upon the bottom as a sub-aqueous plant, to be increased in size by accretions from passing frazil, spiculæ, or crystals. If these spiculæ attach themselves to the stones of a rapid, as they appear to do, the inference is that they lay the foundation of the anchor ice and build it up in the deeper water whenever extreme weather (and probably extreme radiation as the result of it) brings the bottom into a sufficiently cold or "magnetic" condition to attract and hold the passing ice crystals. I have seen the river below the Lachine Rapids when the thermometer was twenty below zero so thick with ice spiculæ that their resistance to the paddle could be felt, and when this paddle was withdrawn, the needle-like spiculæ *stood out at right angles* to it, attached only by the point, like iron filings to a magnet.

In smaller shallow streams the growth is rapid and sometimes such as to drive the stream out of its banks. In Scottish burns it may be seen on the bottom in shallow water, except under the arches of a bridge; and a passing cloud has been known to cause it to rise, presumably by arresting radiation for the moment. But in the colder climate of Canada I have been prevented from re-crossing a stream which I had forded a few days before by its being filled up with at least four feet of anchor ice. There was no bridge in reach, and it would have been dangerous to have attempted to ride through. It is quite conceivable that anchor ice can drive a river out of its bed—cause a winter overflow and the opening of a new channel around a rapid. This possibility may account for some of the "ancient channels," "lost channels," and "high water channels" to be found in the immediate vicinity of some cataracts, chutes, and rapids.

The accumulation, in the deep water at the head of Lake St. Louis, of anchor-ice which is manufactured in the sixteen miles of rapid water between Lakes St. Francis and St. Louis, attained in 1887 a depth of eighty-five feet below the surface-ice, forming a hanging dam, which in severe winters drives a portion of the St. Lawrence water into the Lake of Two Mountains (a part of the Ottawa river), sending the blue-green water of the former to mix with, or rather displace, the amber-brown of the latter in the branches of the Ottawa which flow behind Montreal.

In January, 1857, the St. Lawrence, above the Lachine Rapids, was raised four feet in a few hours by an anchor ice dam upon those rapids, and an anchor ice growth of several feet in depth on the bottom in the open water above the rapids, when it overflowed the aqueduct of the Montreal Water Works; a few feet more would have overflowed all the river bank down to Montreal.

The Royal Commission of 1886 came to the conclusion that the only remedy for ice floods was by reducing the quantity of ice which descended below the Lachine Rapids by means of a boom supported by piers across the foot of Lake St. Louis; or by retarding the formation of the ice bridge as long as possible, but as both would be experiments they advised as the only certain protection for Montreal the construction of the dyke which has been, this year, the means of preventing a flood. The cost of piers and boom for Lake St. Louis was estimated at $70,000. This lake, after having been frozen over, sometimes breaks up in a winter thaw with an easterly gale, when all its ice may descend below; it also may, before it is closed in its channel, have its bordage ice broken off by wind and sea and sent below Montreal. The value of a boom in arresting floating ice and in causing ice to take in a current where freezing over would be delayed until the coldest weather, or not take place at all, has been proved by experience on the Ottawa River, where an ice bridge is formed by the lumbermen with the aid of a boom in positions where it could not otherwise be obtained.

The fitting up of some harbour tugs as ice-breakers was authorized by the Government, late in 1885, for the purpose of preventing the formation of the ice bridge, and passing the floating ice into tide water, but the tugs were frozen in before they could be prepared for this winter work; and the third flood in succession having taken place after this, the dyke was constructed as the only certain protection before another winter could form an ice bridge or threaten a flood. Notwithstanding their recommendation of the temporary dyke, as securing protection, the Commissioners expressed the opinion that this experiment should yet be made on account of its bearing on the question of the permanent dyke at Montreal, as well as its effect on the parishes so often flooded below that city.

An experiment was made in March, 1887, in view of a threatened flood (which took place in the following month) in order to ascertain the possibility of loosening an ice blockade by means of explosives. Eight hundred holes were made and over two tons of explosives (chiefly dualine) were fired about ten feet below the surface. The experiment (which cost nearly $2,500) was a failure, chiefly, as it is believed, in consequence of the great depth of frazil under the surface, cushioning and preventing the transmission of a blow to the surface ice.

Winter Navigation.

The recommendation of the Flood Commission in 1886, which was approved by the Government of the day but could not then be carried out, was that the harbour tugs should be fitted out as "ice-breakers"—at an estimated cost of about one thousand dollars each, and employed to prevent the formation of the ice bridge at Lake St. Peter, as long as possible, or as long as necessary to reduce the ice pack below Montreal, and thus remove all danger of a flood. Had it been carried out and proved successful a dyke might not have been considered necessary. The greater value of an open channel (if only for half the winter) is that it would protect all the river below the Lachine Rapids from both winter and spring ice floods—whereas the dyke is a local proteetion work the cost of which was unimportant in proportion to its value to Montreal.

The winter open channel below Montreal was then suggested as a remedy for flood proteetion only, but was so important in the opinion of the Royal Commission that, even after the completion of the dyke, they advised that this experiment should yet be made. No action has since been taken in this direction, but, as the temporary dyke is over ten years old, and nothing has yet been done toward a permanent one in front of the harbour,—nor is probable before at least another year—it would be well worth the cost that such an experiment as that proposed and sanetioned in 1886 should be made, in the eoming winter, not only as an element of flood protection but of winter navigation, or for extending the navigation season into the winter.

It is in this view that I have devoted so much space to the ice phenomena in this section. There is every reason to believe that if the descending ice could pass freely into tide-water, as it does over the Lachine Rapids, the channel from thence to Lake St. Peter (or at least that part of it below Victoria Bridge) would remain as open and undergo as little change of level as the five miles between those rapids and Lake St. Louis. It has been shown that this channel below Montreal does not freeze over as does the St. Lawrenee above Prescott, but is covered with drift ice from above. That it would not freeze over if this drift ice passed on to tide-water we have a guarantee in the winter conditions where the St. Lawrence does not freeze over, and is not covered with drift ice and where the surfaee inclination and strength of current is less. The five miles above the Long Sault Rapids, between Dickinson Landing and Farran's Point, is generally open water, although in severe winters it may be covered by drift ice from above, which may be stopped by an iee-bridge purposely floated out from the shore in order to reaeh Croil's Island. It has a rate of inclination of six-tenths of a foot in the whole distance, or one and one-fifth inch per mile. The surface inclination below Montreal is greater than this in the 50 miles to Lake St. Peter, and therefore, if an

ice bridge were prevented from forming, and the descending ice from stopping, an open channel would be the result.

In the winter of 1885-6 the ice did not stop in the channel anywhere below Three Rivers—and if the ship channel through Lake St. Peter and the Sorel islands had then been kept open the descending ice would most probably have all passed into tide-water. Apparently the only difficulty would be in Lake St. Peter, where the broken ice might be held in by a strong wind for some time, but as there is a current of about one mile per hour through this channel it would soon be emptied of its ice, if the latter were kept broken.

It would be necessary to prevent the formation of an ice bridge below Three Rivers if the channel is to be kept open for navigation ; but this, on account of the tide, should be a less difficult undertaking than with the channel in Lake St. Peter. The Grand Trunk Railway has for many years maintained a winter ferry at Quebec, which has been occasionally interrupted by an ice bridge, only, as I believe, for lack of any attempt to prevent the formation of one. Occupied with their constant service, they have been unable to pay attention to what has been going on above or below them. It is a case of "*principiis obsta*" ; to be stifled, like a fire, at the first inception.

ICE BREAKERS.

The Straits of Mackinaw, Lake Michigan, and the City of Duluth, Lake Superior, are in the same latitude as the St. Lawrence below Montreal, and being farther from tide-water, have at least as severe a climate. Ice forms three feet thick in the harbour of Duluth, and a channel is broken and kept open by a steel tug, 80 feet long, 18 feet beam, with an engine 20 inches by 20 inches, and a cutaway forefoot to get on top of the ice and break it down.

At the Straits of Mackinaw large and powerful steam car-ferry steamers, especially constructed for the service, maintain a railway ferry eight miles long from dock to dock throughout the winter. The ice here usually forms in Lake Michigan, and is blown into the straits and blocked against islands in Lake Huron—and closes the straits for about four months. The thickness of ice ranges from two to four feet, according to the amount of zero weather during the winter. The car-ferry steamer readily breaks through ice which is two feet thick at a speed of eight miles per hour ; and has to contend with "windrows" of ice formed by floes driven in from the lake and piled upon each other, sometimes twenty-five to thirty feet thick—which may also be grounded at the harbour entrance. These are worked through by the aid of a bow propeller, which is reversed and throws a current from the wheel into the pack, tearing it apart. The ice is crushed by the spoon-shaped prow of the

boat riding upon it, and is caught by the current of forward wheel and passed under the side ice and boat, which breaks a channel ten feet wider than herself. The forward screw forces the broken ice away from the bows of the boat, which is held up to this work by the stern propeller, which last has double the power of the forward one.

The first ice-breaker which succeeded in maintaining a car-ferry through the ice across the Straits of Mackinaw was the "St. Ignace," built in 1889. Her dimensions are 230 x 50 x 24, draught, light, 14½ feet, loaded 16½ feet. Her engines are 3,000 horse power, and she has two propellers. She carries ten forty-ton cars, and is 1,200 gross tons.

The "Ste. Marie" was added in 1893. She is 302 x 51½ x 24, with 1,357 gross tons. Forward propeller 10½ feet diameter, after one 12½ feet.

The hulls of these are wood sheathed with steel. The rear propeller has double the power of the forward one.

There are other winter car-ferries on Lake Michigan, one over fifty and another over sixty miles in length, which break their way in and out of harbours through ice over two feet thick, and contend with windrowed ice five to ten feet thick in the open lake.

The car-ferry steamer "Père Marquette," running across Lake Michigan, between Manitowoc and Ludington (53 miles) is 350 feet long by 56 feet wide, has four tracks, carrying thirty cars with 1,350 tons, besides 200 tons coal. She draws 14 feet and has twin screws 11 feet in diameter, giving a speed of 13 knots per hour. Weight of steel in her hull, 2,700 tons. Her horse power is 3,500.

An ice-breaking steamer recently built for Russia, in Denmark, is reported to have gone at a rate of three knots per hour through ice from two to four feet thick ; she is intended for the harbour of Vladivostock.

Russia is now building, in England, a gigantic ice-crusher, at a cost of $875,000, for maintaining winter navigation from the Baltic to Cronstadt and St. Petersburgh, and summer navigation in the Kara Sea in order to reach Northern Siberia. This boat will have 10,000 horse-power, 5,000 tons coal capacity, double bottom and double skins, three feet apart, with four sets of engines working the forward and aft propellers.

A winter ferry has been maintained between Prince Edward Island and the mainland, with, for short periods, more or less difficulty, and another winter ferry in the Gulf of St. Lawrence has connected the railway system of Newfoundland with that of Canada during the last winter by a boat built for the route in Scotland.

It is at least doubtful if anywhere in the St. Lawrence greater difficulties would be encountered than those which have been so successfully overcome, for the last nine years, on Lakes Michigan and Superior, where there is no assistance from current or tide to carry off the broken ice.

The most valuable wheat in the world is grown upon the Canadian prairies—but at the greatest distance from its market, and is barely harvested to escape the frost. It needs, therefore, from its remoteness the greatest economy in transportation, and from its late arrival at Montreal the longest possible extension of navigation from that seaport. The early closing of the St. Lawrence has been given as a reason why 75 per cent of our Manitoba wheat was exported from New York last year and only 25 per cent from Montreal. Whether this is correct or not, there can be no difference of opinion as to the importance to Canada of an extension of the length of the season of navigation, if only for one month, and also as to the value of the earliest possible re-opening of navigation in the spring, which would follow a diminished ice-pack.

The winter navigation of the Lower St. Lawrence is, in these days of steel and quadruple expansion, practicable ; and we cannot say how soon it may be profitable or necessary. It may be found more so than the summer navigation of Hudson Straits, which we have been (and are still) investigating, and where a summer ice-fighter may be as necessary as in the Kara Sea.

An open channel in winter would prevent the flooding of parishes below Montreal and would be invaluable for defence, or in case of interruption to transit from United States seaports.

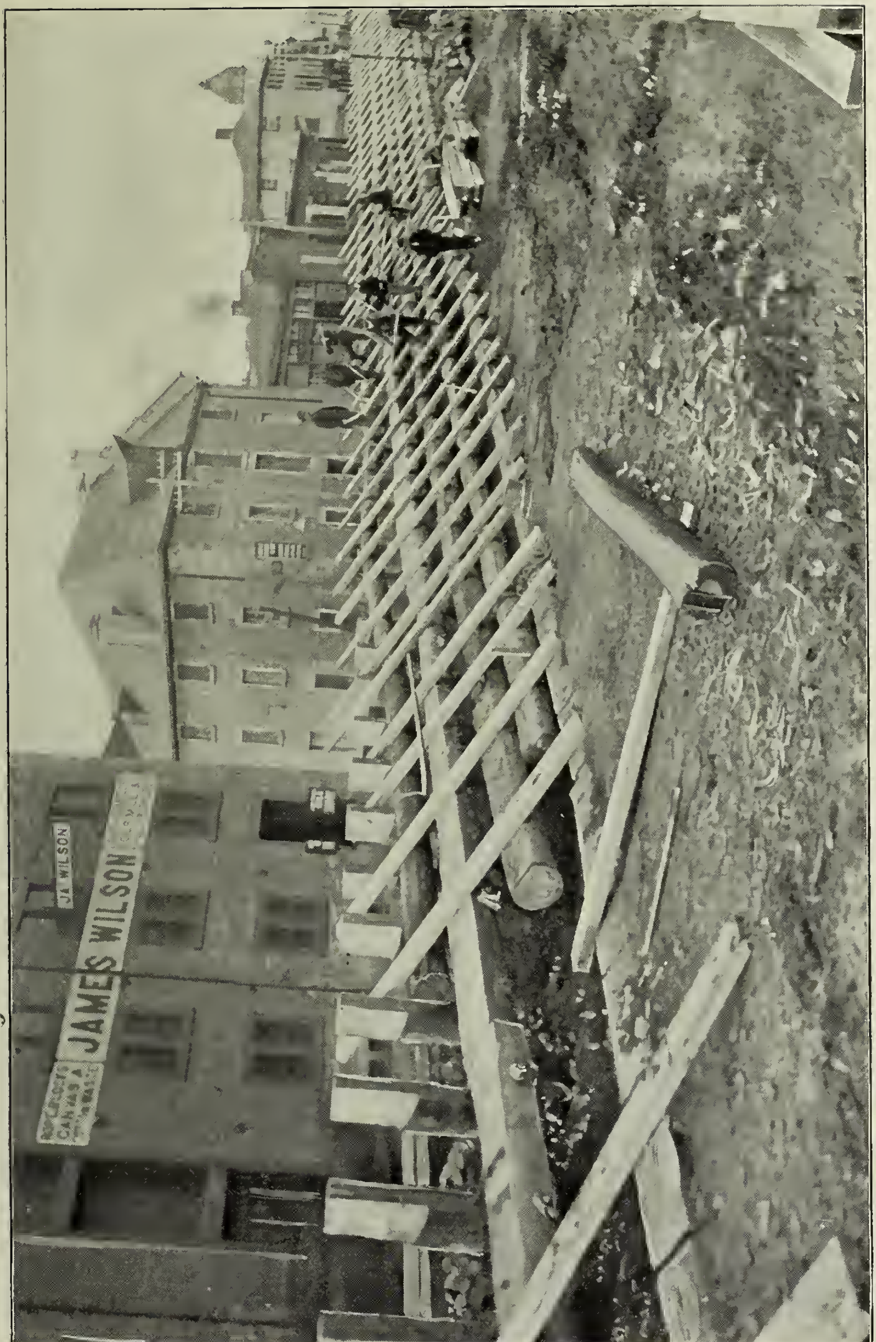
The experiment, if made at all, should be carried out with a sufficient number of ice-breakers and coal stations to secure a thorough test under the most unfavourable conditions of weather, so that with the experience gained the minimum number and the most efficient plan of boat for the purpose may be ascertained.

ICE "SHOVE," MONTREAL, BEFORE CONSTRUCTION OF GUARD PIER).

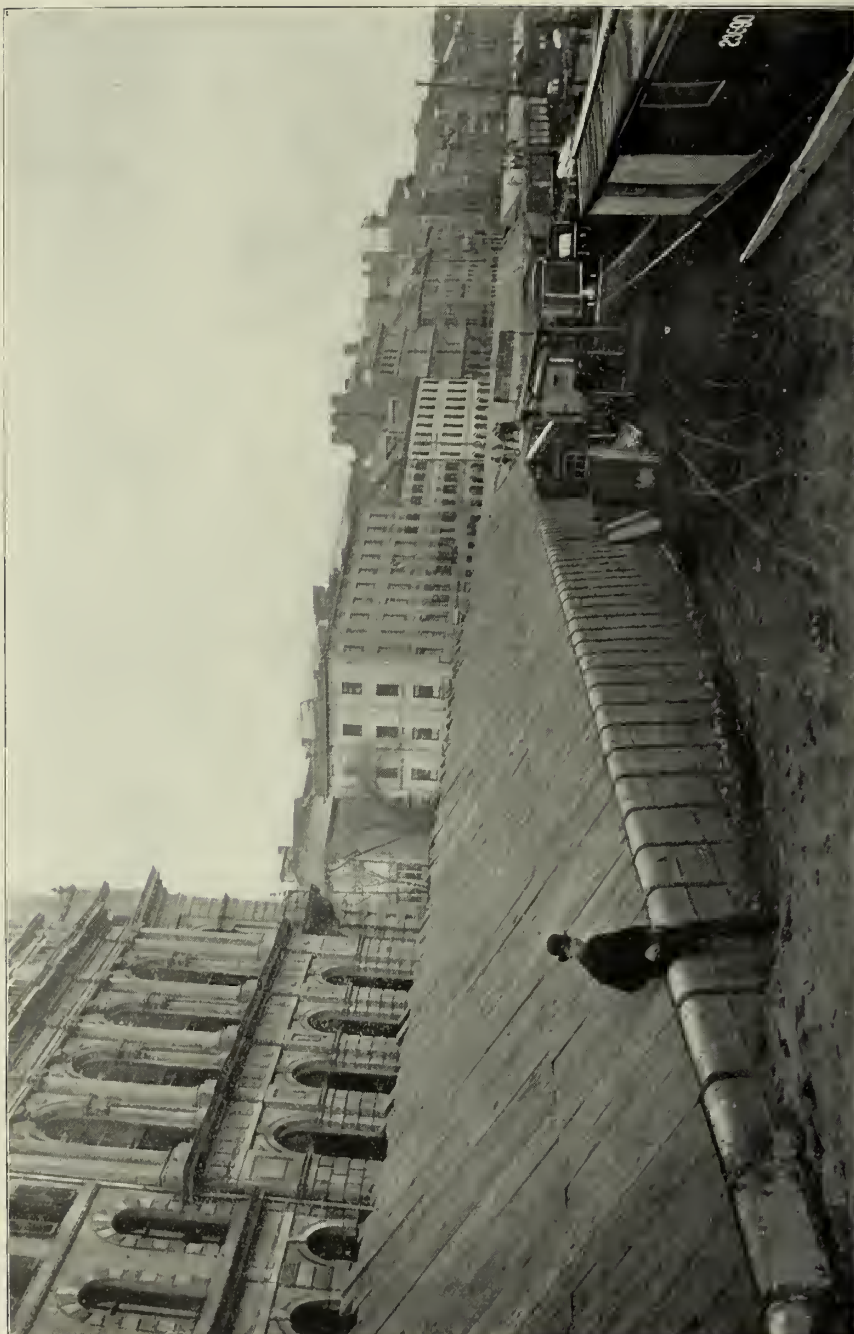
ICE "SHOVE," MONTREAL, BEFORE CONSTRUCTION OF GUARD PIER.

ICE "SHOVE," MONTREAL, IN FRONT OF BONSECOURS MARKET (BEFORE THE CONSTRUCTION OF THE GUARD PIER).

ICE "SHOVE," MONTREAL, BEFORE CONSTRUCTION OF GUARD PIER.



TEMPORARY DYKE, MONTREAL, UNDER CONSTRUCTION, 1887.


TEMPORARY DYKE, MONTREAL, COMPLETED 1887.

ICE "SHOVE," MONTREAL, STOPPED BY TEMPORARY DYKE (FRONT VIEW).

ICE "SHOVE," MONTREAL, STOPPED BY TEMPORARY DYKE (REAR VIEW).

RAILWAY TRACKS CROSSING ST. LAWRENCE ON THE ICE BELOW MONTREAL.

WINTER RAILWAY BRIDGE OVER ST. LAWRENCE BELOW MONTREAL.

MACKINAW CAR FERRY ICE BREAKER GOING THROUGH THREE FEET OF ICE

MACKINAW CAR FERRY STEAMER GOING THROUGH TWO FEET OF ICE.

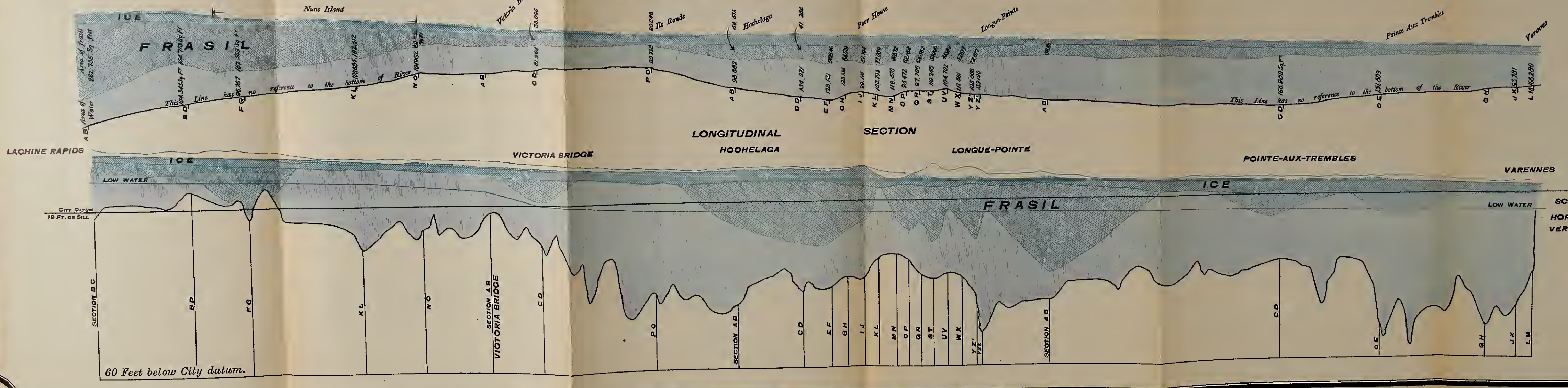

VELLING,
ST. LAWRENCE,
AND LACHINE.
KEL,
CHARGE.
TRUE NORTH
POINTE du LAC
Tide Ends
Port St Francis
Line of Beacons
Nicolet Rv.
CHAS CHALONER, DEL'T.


GEODETIC L ELLING,
WATER LEVELS RIVE ST. LAWRENCE.
QUEBEC TO MONTREA AND LACHINE.
BY
R. STEC EL,
ENGINEER IN CHARGE.
YAMACHICHE
CHANNEL.

PLAN No. 2

DIAGRAM SHOWING DISTRIBUTION OF FRASIL AND REMAINING FREE WATER WAY, MARCH 15TH. 1887.

Ideal Profile, from Cross Sections taken, shewing uniformity of free water way under all conditions of breadth and depth of River and disposition of its Frasil.

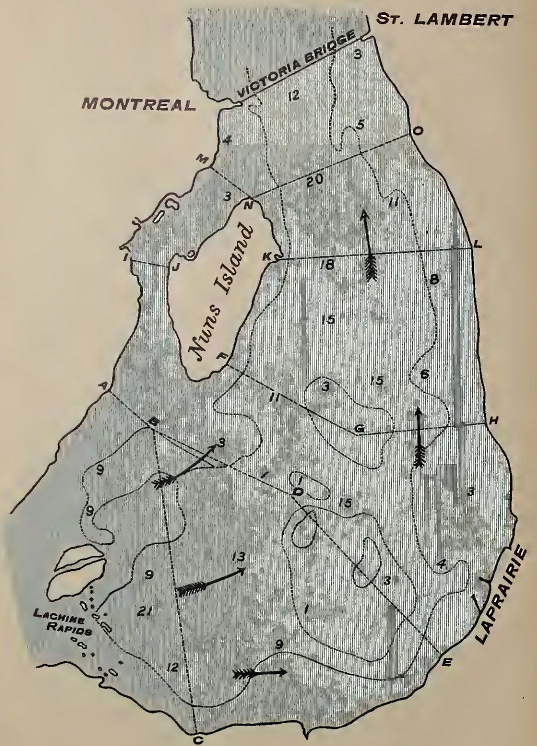


SCALES OF DIAGRAM

HORIZONTAL:— 4000 *feet to an Inch.*
VERTICAL: — *Cross sectional areas of Frasil and free water way are plotted under Ice at* **200,000** *Sq. ft. to an Inch.*

SCALES OF LONGITUDINAL SECTIONS.

HORIZONTAL	4000 *feet to an Inch.*
VERTICAL	20 " " " "



PLAN No. 3

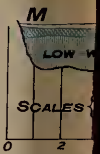
Montreal Flood Commission,

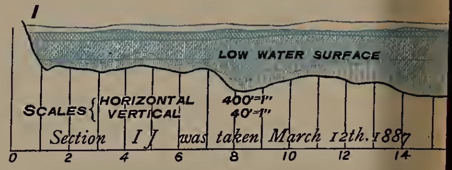
CROSS SECTION SHOWING FRASIL, ICE AND SNOW,

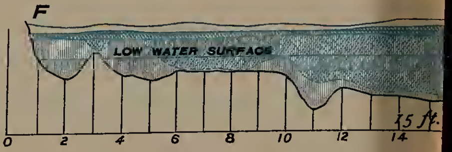
LACHINE RAPIDS TO VICTORIA BRIDGE,

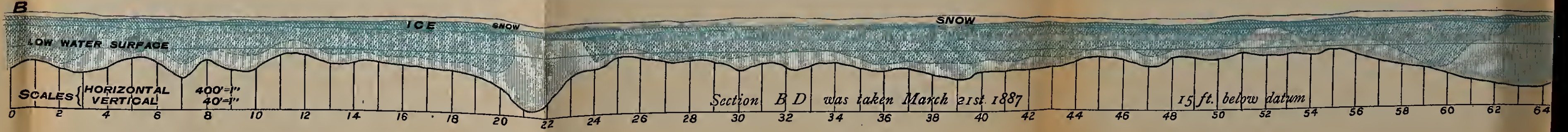
WINTER OF 1886-7.

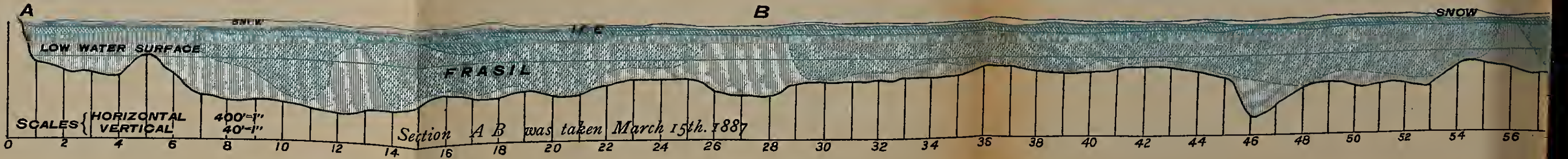
Low water—At the stage of assumed low water, there is a depth of 17 ft. on the lower sill of old Lock No. 1 Lachine Canal, or 11 ft. on the flats of Lake St. Peter.

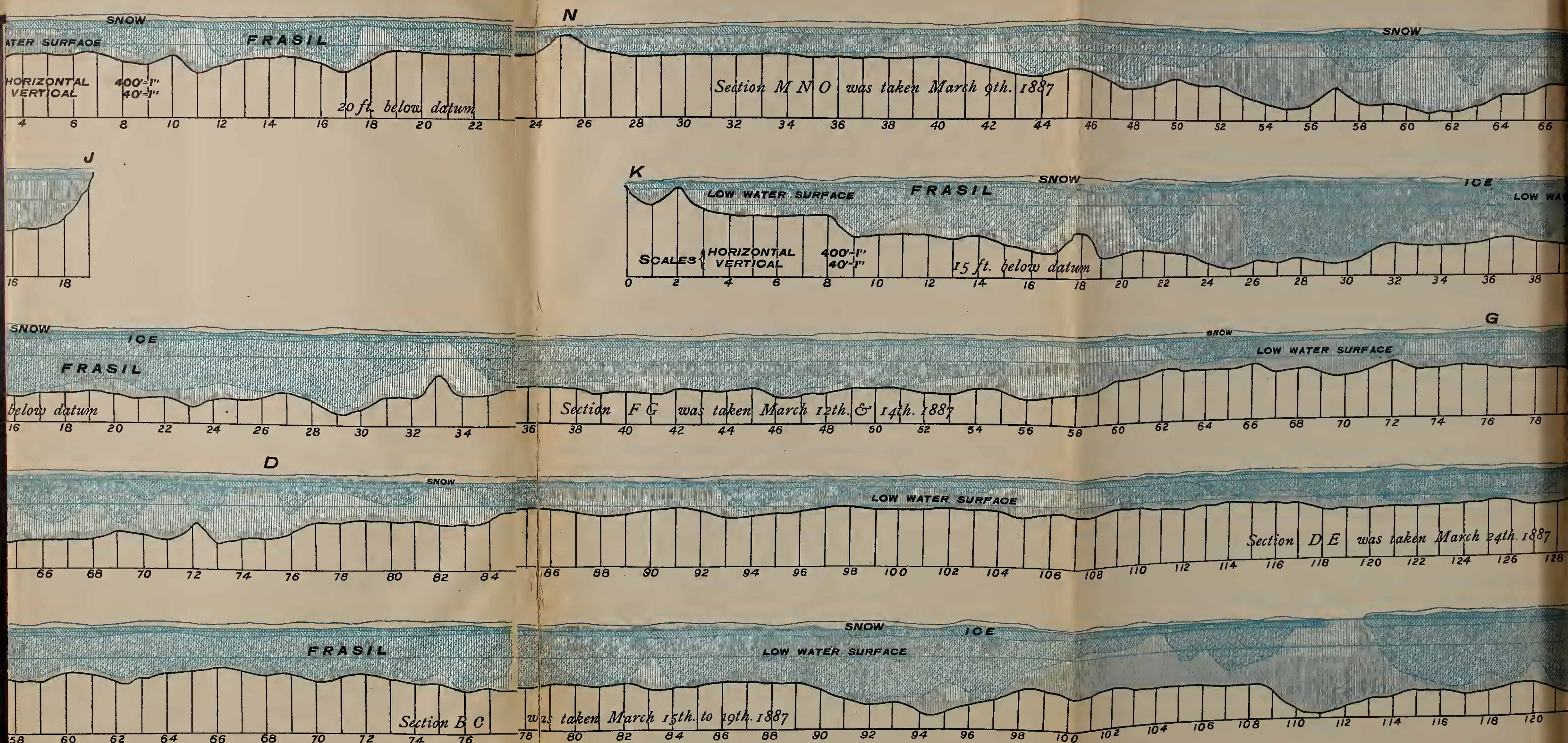




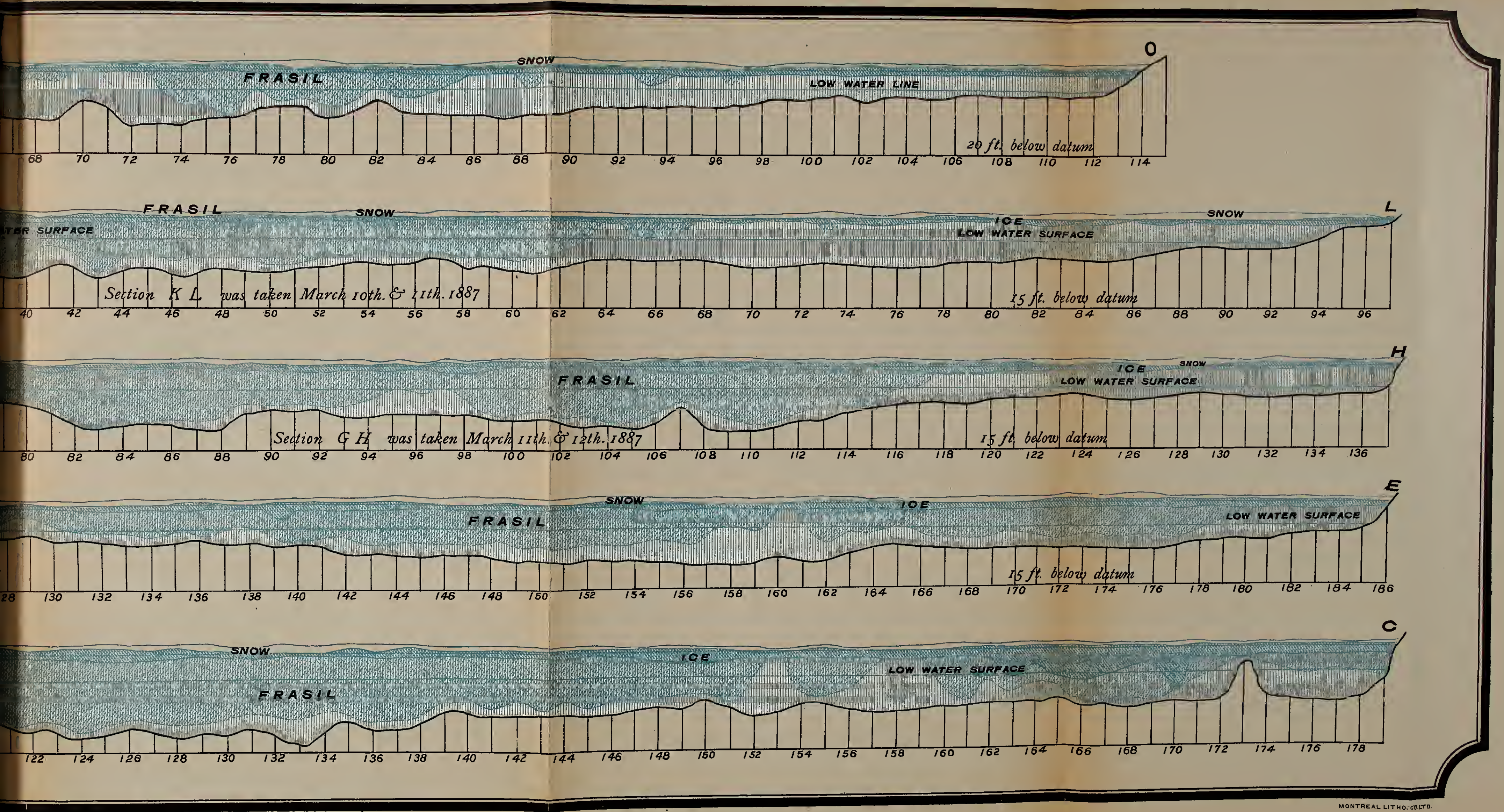








SNOW
FRASIL
ATER SURFACE
HORIZONTAL 400'=1"
VERTICAL 40'=1"
20 ft. below datum
N
Section M N O was taken March 9th. 1887
J
K
LOW WATER SURFACE
ICE
SCALES HORIZONTAL 400'=1" VERTICAL 40'=1"
15 ft. below datum
below datum
G
Section F G was taken March 12th. & 14th. 1887
D
Section D E was taken March 24th. 1887
Section B C was taken March 15th. to 19th. 1887



MONTREAL LITHO. CO. LTD.

Low water — At the stage of assumed low water, there is a depth of 17 ft. on the lower sill of old Lock No. 1 Lachine Canal or 11 ft. on the flats of Lake St. Peter.

MONTREAL FLOOD COMMISSION,

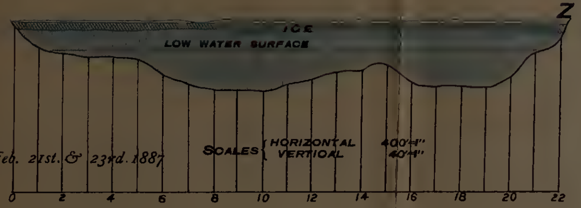
CROSS SECTION SHOWING FRASIL, ICE AND SNOW,

HOCHELAGA TO LONGUE POINTE

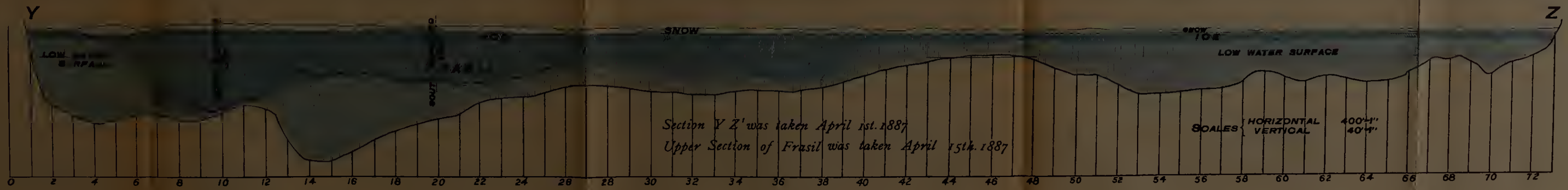
WINTER OF 1886-7.

PLAN No. 4

Section Y Z' was taken Feb. 21st. & 23rd. 1887



Key Plan--Scale 6000'-1"



Section Y Z' was taken April 1st. 1887
Upper Section of Frasil was taken April 15th. 1887

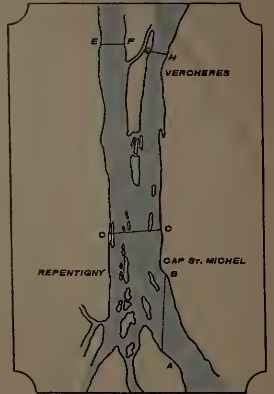
Montreal Flood Commission,

Cross Section Showing Frasil, Ice & Snow,

Varennes to Vercheres..

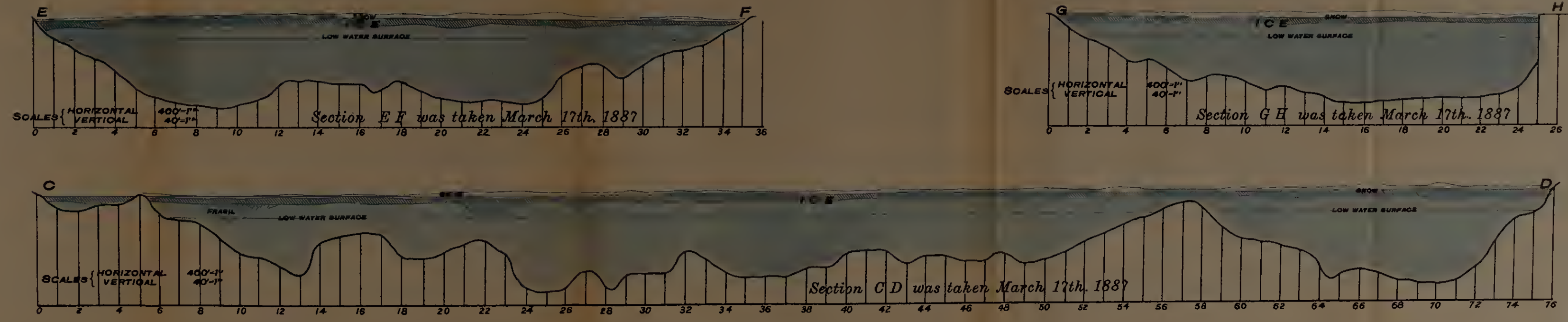
Winter of 1886-87.

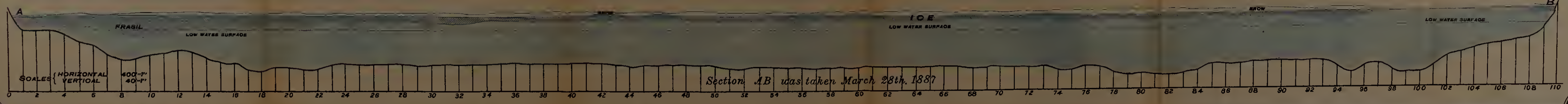
PLAN No. 5



Key Plan 12.000"-1"

Low water—At the stage of assumed low water, there is a depth of 17 ft. on the lower sill of old Lock No. 1 Lachine Canal or 11 ft. on the flats of Lake St. Peter.





MONTREAL LITHO

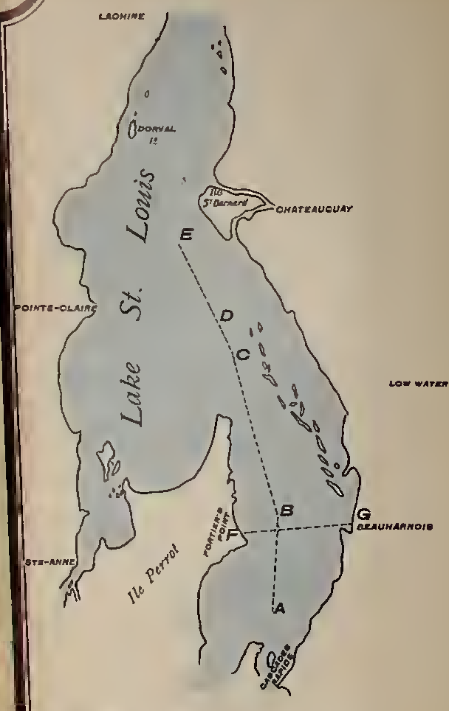
PLAN No.6

MONTREAL FLOOD COMMISSION,

LONGITUDINAL AND CROSS SECTIONS.

LAKE ST. LOUIS,

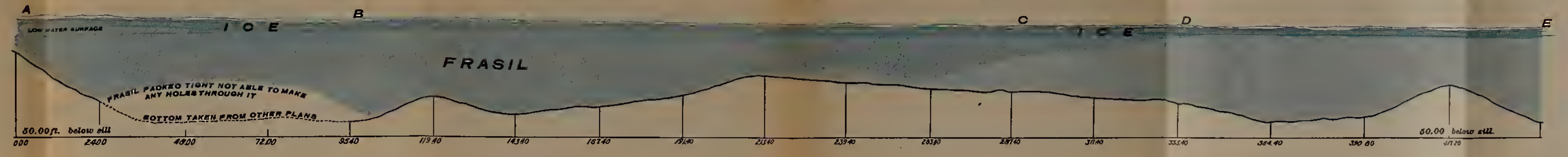
MARCH, 1887.



Scale, 12000 feet to an inch.

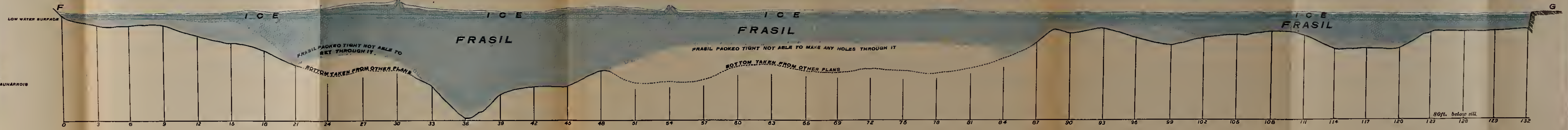
LONGITUDINAL SECTION

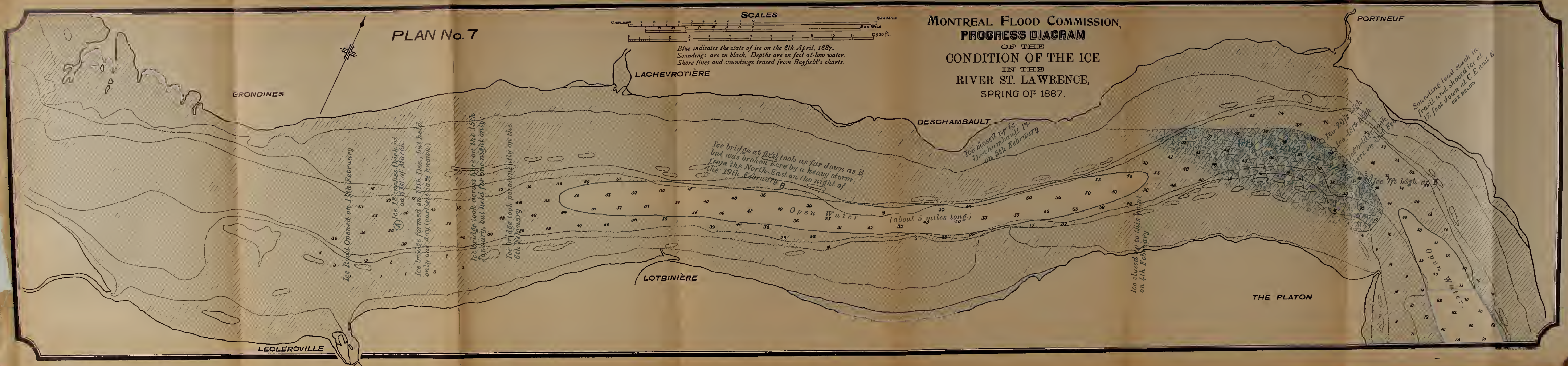
SCALES { HORIZONTAL 2000 FT. TO AN INCH; VERTICAL 40 " " " "



CROSS SECTION

SCALES { HORIZONTAL 400 FT. TO AN INCH; VERTICAL 40 " " " "





PLAN No. 7
SCALES
CABLES
SEA MILE
ENG MILE
12000 ft.
Blue indicates the state of ice on the 8th April, 1887.
Soundings are in black. Depths are in feet at low water.
Shore lines and soundings traced from Bayfield's charts.
MONTREAL FLOOD COMMISSION,
PROGRESS DIAGRAM
OF THE
CONDITION OF THE ICE
IN THE
RIVER ST. LAWRENCE,
SPRING OF 1887.
GRONDINES
LACHEVROTIÈRE
DESCHAMBAULT
PORTNEUF
LOTBINIÈRE
LECLERCVILLE
THE PLATON
Ice Road Opened on 14th February
Ice 18 inches thick at on 31st of March.
Ice bridge formed on 11th Dec., but held only one day (earliest case known)
Ice bridge took across here on the 15th January, but held for one night only
Ice bridge took permanently on the 6th February
Ice bridge at first took as far down as B but was broken here by a heavy storm from the North-East on the night of the 19th February B
Ice closed up to Deschambault Pt on 5th February
Open Water
(about 5 miles long)
Ice closed up to this point on 4th February
Ice 20ft high
Ice 15ft high
Ice bridge took here on 2nd Feb
Ice 7ft high at E
Sounding lead stuck in frasil and shoved ice at 12 feet down at C E and E
SEE BELOW
Open Water